NISTIR 6527

Measurement Needs for Fire Safety: Proceedings of an International Workshop

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U.S. Department of Commerce
William M. Daley, Secretary

Technology Administration
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Measurement of Smoke Aerosol

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April 6, 2000

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Current Motivation for Smoke Measurements

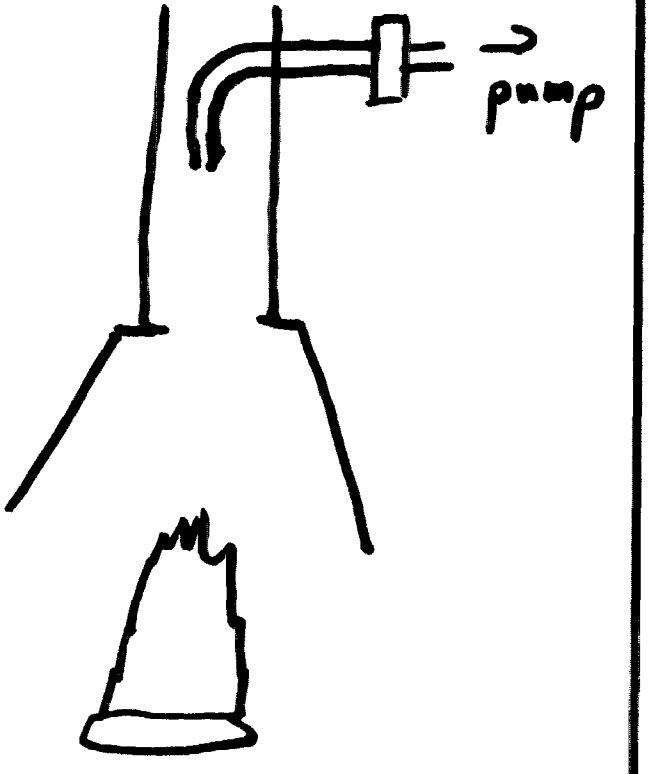
- Reduction in nuisance alarms from smoke detectors
- Improved plastics with less smoke production
- Validation of models for smoke flow/dispersion
- Development of sub-grid flame radiation model

Mass Concentration via Sampling and *in situ* Measurement

- Post-flame
- In-flame
- Distributed

Post-Flame Sampling from a Duct

Lowest Expanded Uncertainty - 4 %
Typical Uncertainty - 10 %



- Isokinetic sampling
- Thermophoretic losses
- Filter efficiency
- Flow control/calibration
- Uniformity of smoke
- Filter weighing

Bouguer's Law

- *relates light intensity ratio I/I_s to the mass concentration smoke M_s and pathlength L.*
- *assumes σ_s is independent of size or structure of the agglomerate.*

$$\frac{I}{I_0} = exp(-\sigma_s M_s L)$$

Recommended Value of σ_s for Smoke Produced by Overventilated Flaming Combustion of Materials in Buildings

8.7 m^2/g

Expanded Total Uncertainty: $\pm$ 1.1 m^2/g

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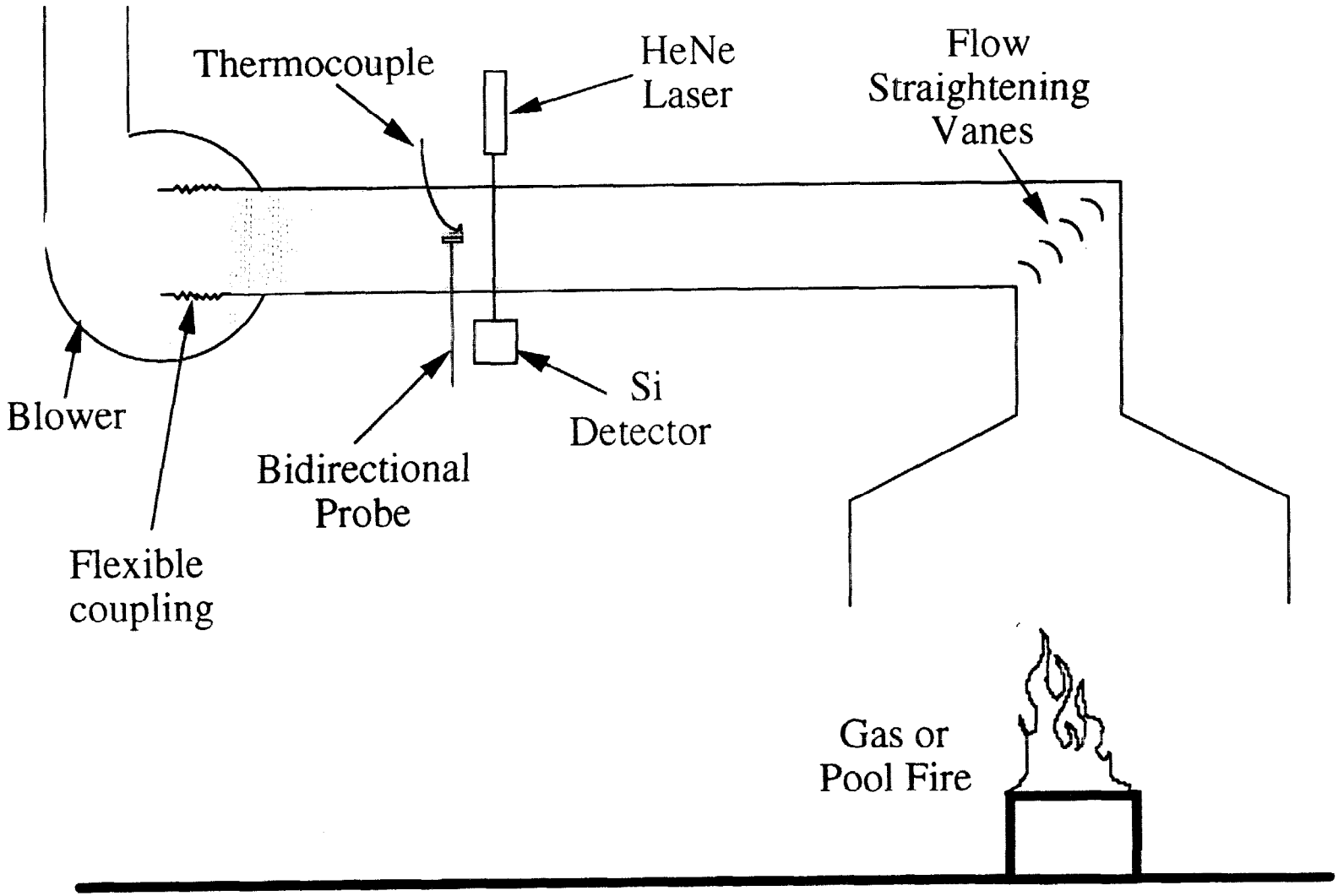
Smoke Meter Overview



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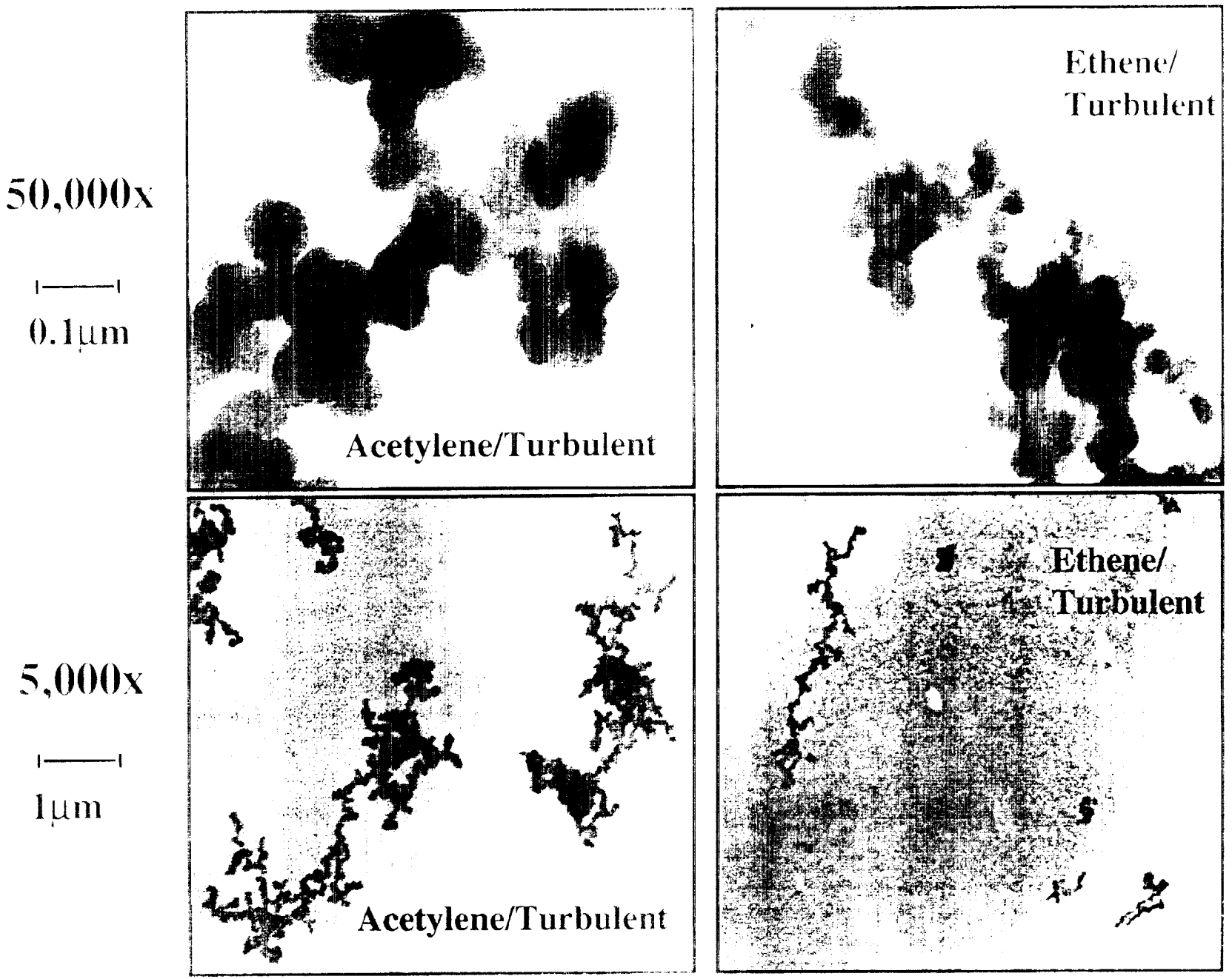
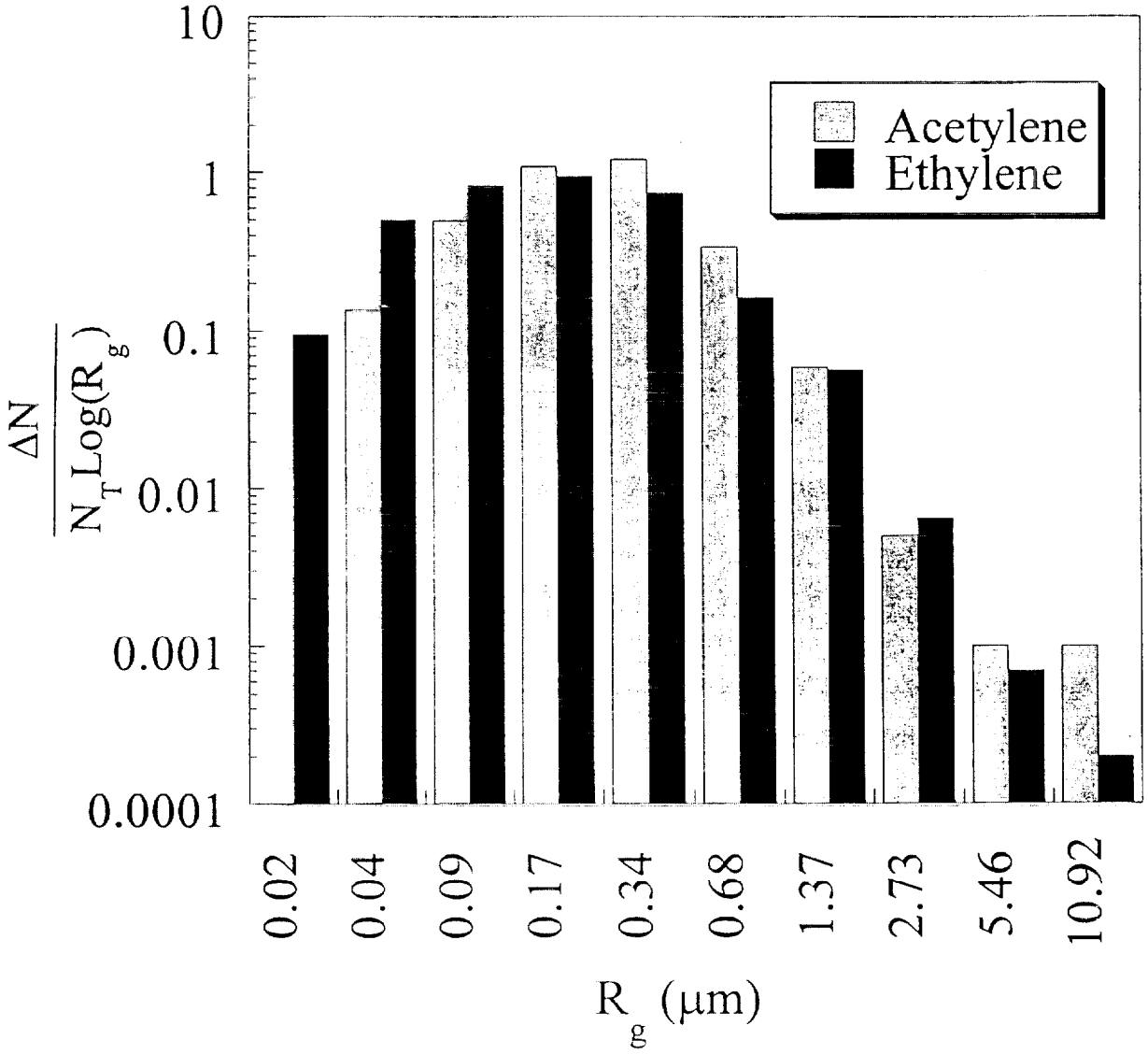
Particle Size Distribution for Soot

Soot Aerosol

- TEM analysis, labor intensive
- Cascade impactor - requires weighing eight samples for each size distribution
- There is no widely used *in situ* method for measuring the agglomerate size


50,000x
0.1μm
Acetylene/Turbulent
Ethene/
Turbulent
5,000x
1μm
Acetylene/Turbulent
Ethene/
Turbulent

Zhy Choi, Mulholland, Critzo



Evans et al, In-Situ Burning at Oil Spills: Mesoscale Experiments (1992)

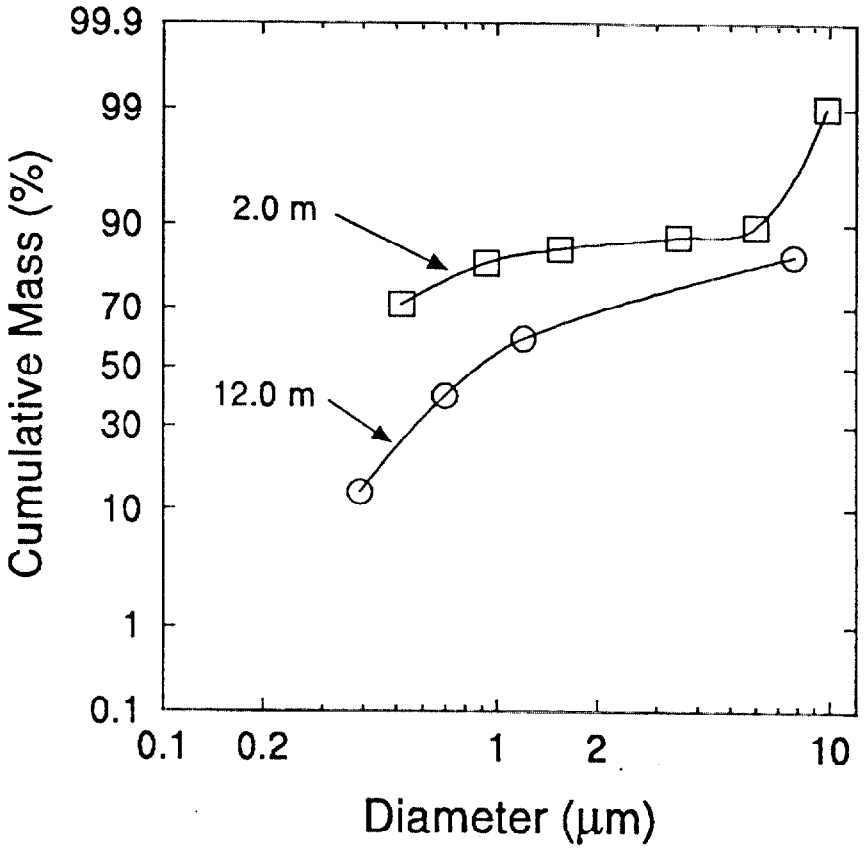
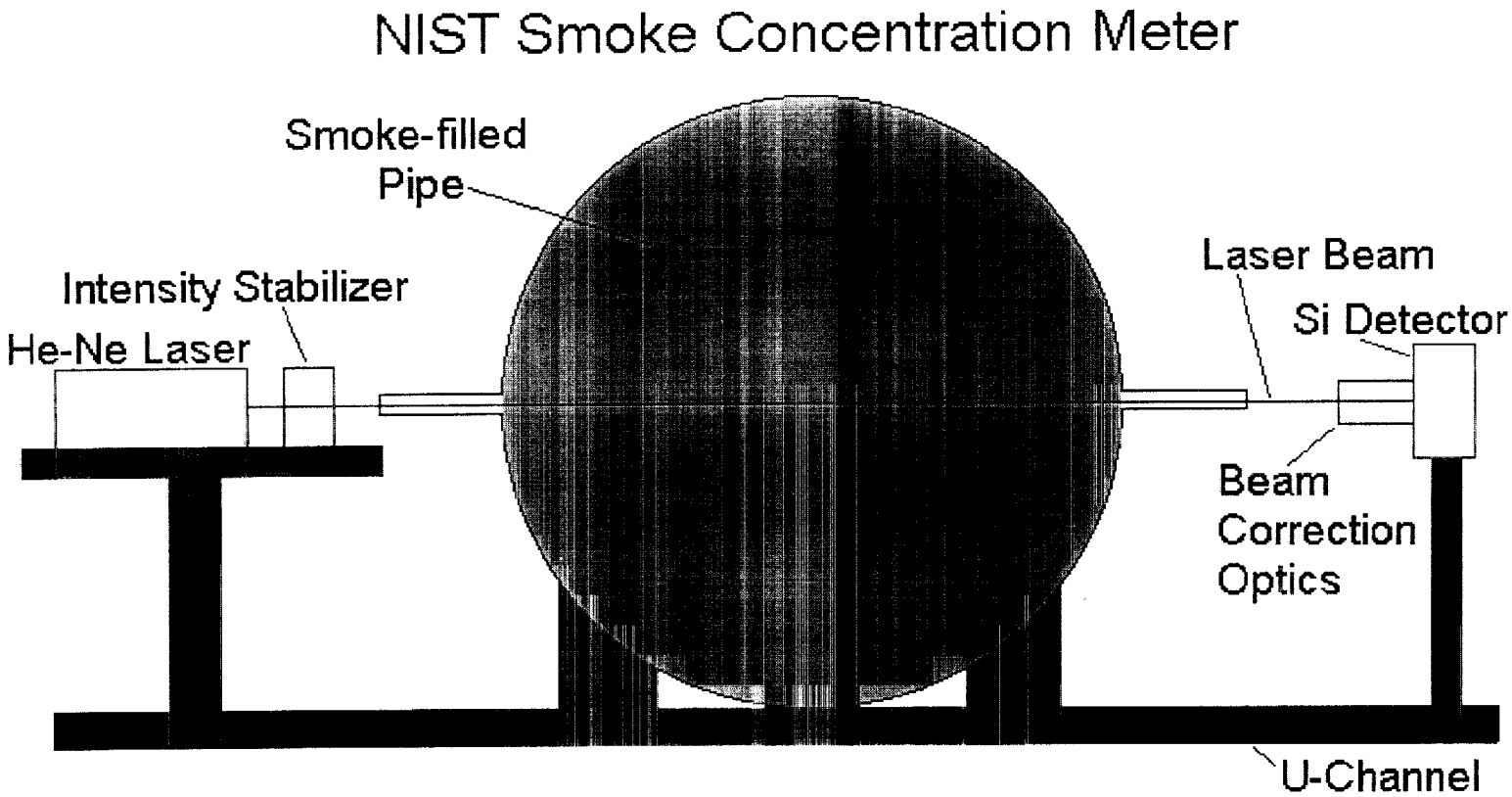
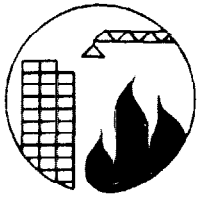


Figure 10. **Size distribution of smoke particulate from a 2.0 m diameter Murban crude oil fire and a 12.0 m diameter Louisiana crude oil fire**


NIST Smoke Concentration Meter
Smoke-filled
Pipe
Intensity Stabilizer
He-Ne Laser
Laser Beam
Si Detector
Beam
Correction
Optics
U-Channel



Major Design Features of New Smoke Concentration Meter

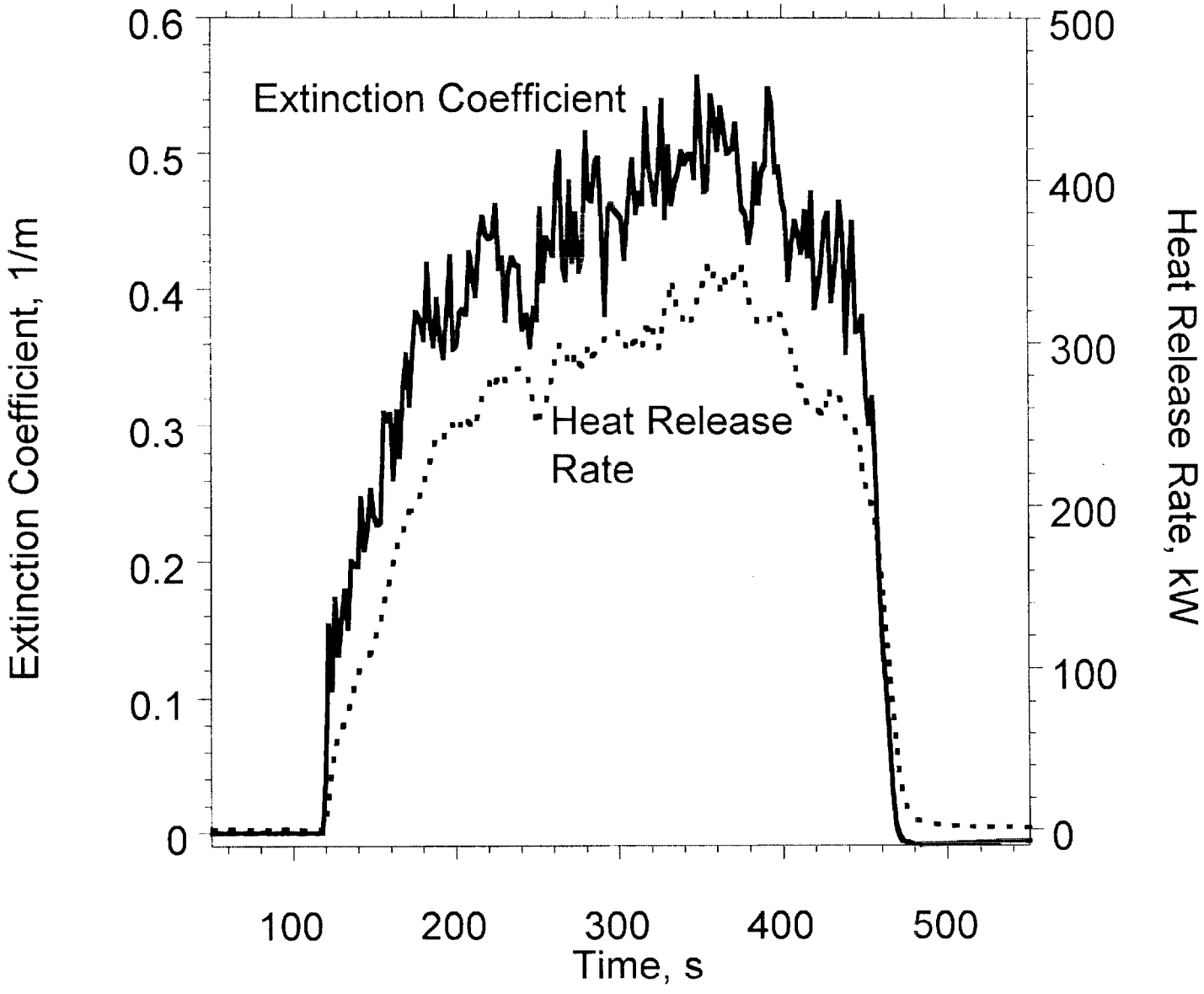
- *Stabilized light source to minimize drift*
- *Purge air to prevent smoke deposition on optics*
- *Focusing lens /diffuser to minimize effect of slight beam deflection*
- *1.2° acceptance angle of detector to minimize the effect of forward scattered light.*
- *Constructed from commercially available components to allow standardization.*

Uncertainty Analysis

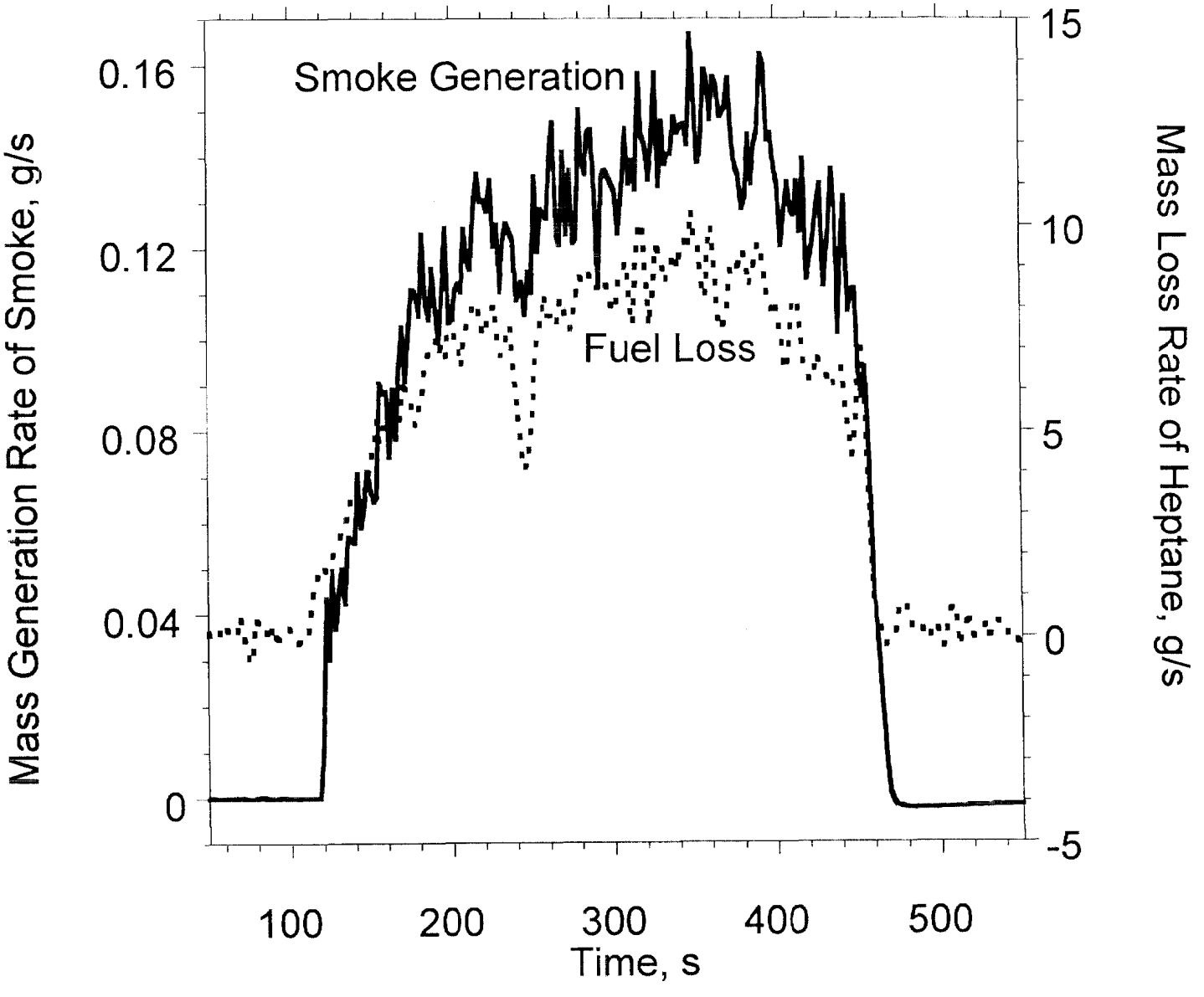
$$Yield = \frac{K \dot{V} C_1}{\sigma_s \dot{m}_f}$$

Variable	Nominal Value	Rel. Std. Uncert., %
K	0.50 m^{-1}	1.6
σ_s	8.7 m^2/g	5.4
flow coeff.	0.83	(4.8)
$\dot{V}$	2.1 m^3/s	5.9
$\dot{m}_f$	10.0 g/s	2.2
C_1 smoke profile factor	0.97	3.0
Total B uncertainty		9.0
Type A uncertainty		5.3
Combined uncertainty		10.4
Expanded uncertainty (95 % confidence interval)		20.8

Extinction Coefficient and Heat Release Rate for a 50 cm Diameter Heptane Pool Fire



Mass Generation Rate of Smoke and Mass Loss Rate of Heptane for 50 cm Diameter Pool Fire



In-flame Sampling

Thermophoretic sampling (Dobbins, Fletcher, Koylu)

- Size distribution of primaries and agglomerates
- Estimate of soot volume fraction
- Laser microprobe analysis of precursor soot

Sampling (Howard)

- Water cooled stainless steel probe
- Most of smoke aerosol collected on sampling probe (with PTFE insert)before filter
- Gravimetric and chemical analysis

In Situ Light Extinction Measurements (Markstein, Sivathanu, Shaddix)

- cooled probe
- 2 - 10 cm path length
- purge air
- fiber optics
- up to at least 1000 Hz with fair sensitivity
- Total uncertainty ?
- Applied to large pool fires (1 m or larger)

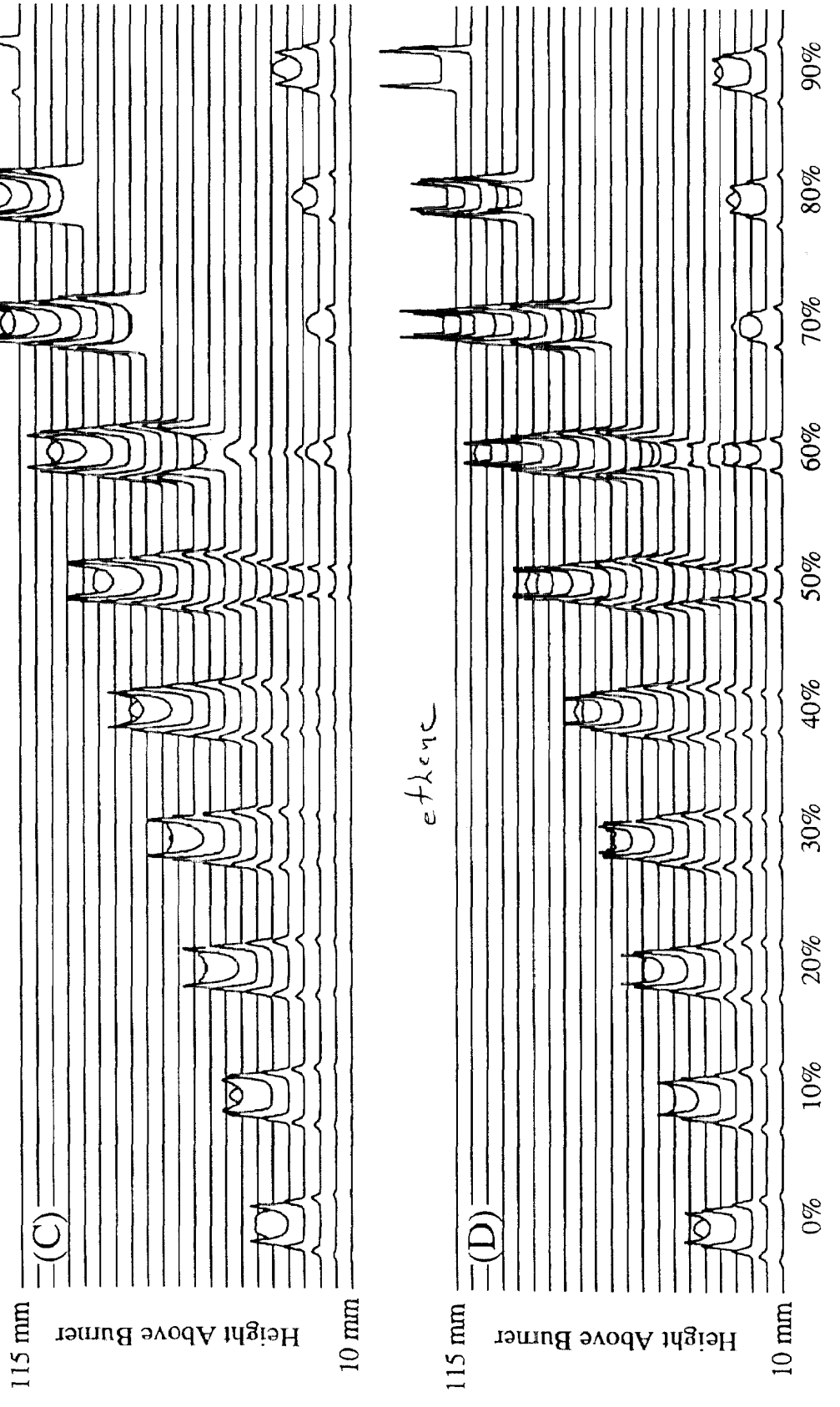
Spatially Resolved Soot Measurements (Smyth, *et al.*, van der Waal, Choi)

Light scattering - 2D distribution of scattering using CCD

Laser Induced Incandescence

- 2D volume fraction distribution with 0.2 mm resolution
- Calibrated versus light extinction and gravimetrically
- less sensitive to early/small soot

Neither method applied to large flames


Propane
ethene
(C)
(D)
Height Above Burner
115 mm
10 mm
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%

Future Challenges

- Round robin comparison of soot production rate using a known soot generation source
- Local (0.5 mm resolution) soot concentration field in turbulent flames for sub-grid model
- Optical diagnostic for agglomerate size (radius of gyration)